

Comparing the aerobic demand of various pieces of accessible exercise equipment in  
individuals with multiple sclerosis

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## Abstract

Current research in the effectiveness of different aerobic exercise modalities for individuals with MS is incomplete. The primary aim of this study is to compare the aerobic response of six selected pieces of accessible exercise equipment at a moderate intensity, as indicated by the current exercise guidelines for individuals with MS. Exercise equipment preference was evaluated using a questionnaire. Participants (n=10) performed a steady-state exercise test on an arm ergometer, arm-leg recumbent stepper, body weight supported treadmill, arm-leg functional electrical stimulation (FES) recumbent stepper, arm FES cycle ergometer, and leg FES cycle. The average  $\text{VO}_2$  ( $\text{ml} \cdot \text{kg} \cdot \text{min}^{-1}$ ) was recorded on each piece of equipment. Here, the body weight support treadmill, arm leg FES recumbent stepper, and the arm leg stepper were significantly more aerobically demanding than the arm ergometer ( $p < .05$ ). Further, there were no differences in pain ( $p > .05$ ), safety ( $p > .05$ ), enjoyment ( $p > .05$ ), or anticipated adherence to exercise guidelines in duration ( $p > .05$ ) or frequency ( $p > .05$ ). In this study, all forms of accessible aerobic exercise were equally aerobically demanding and preferred in individuals with MS, with the exception of the arm ergometer being less aerobically demanding.

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### **Abbreviations**

|                      |  |
|----------------------|--|
| CSEP                 | Canadian society of exercise physiology                      |
| ADL                  | Activities of daily living                                   |
| BWSTT                | Body Weight Supported Treadmill Training                     |
| CNS                  | Central nervous system                                       |
| EDSS                 | Expanded Disability Status Scale                             |
| EPQ                  | Exercise Preference Questionnaire                            |
| FES                  | Functional electrical stimulation                            |
| FES-A                | Functional electrical stimulation arm cycling                |
| FES-L                | Functional electrical stimulation leg cycling                |
| FES-LA               | Functional electrical stimulation arm and leg ergometer      |
| HR                   | Heart rate   |
| HR <sub>max</sub>    | Maximum heart rate   |
| MS                   | Multiple sclerosis   |
| RPE                  | Rate of perceived exertion                                   |
| RRMS                 | Relapsing-remitting multiple sclerosis                       |
| PPMS                 | Primary progressive multiple sclerosis                       |
| SPMS                 | Secondary progressive multiple sclerosis                     |
| SCI                  | Spinal cord injury   |
| VO <sub>2 max</sub>  | Maximum volume of oxygen in liters per kilogram body weight  |
| VO <sub>2</sub>      | Relative Volume of oxygen in liters per kilogram body weight |
| VO <sub>2 peak</sub> | Peak volume of oxygen in liters per kilogram body weight     |

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## **Chapter 1: Introduction**

### **1.1 Rationale**

Multiple Sclerosis (MS) is a neurodegenerative disease of the nervous system that affects motor, autonomic and cognitive functioning in afflicted persons. Global incidence rates of MS are on the rise, particularly in women (Rosati, 2001). In some parts of Canada (Barrhaven, Alberta) prevalence counts have been observed to be as high as 196/100000 (Armstrong, Warren, & Warren, 1991). The natural course of the disease follows a gradual progression of disability, with a 15-year median time for reaching an expanded disability status scale (EDSS) score of 6, indicating those that have the ability to walk with a cane for not more than 100 meters without resting (see appendix A) following onset of the disease (Kremenchutzky, 2006).

Most recently, exercise has been considered a therapeutic requirement for individuals with MS, as some disease symptoms are likely due to a combination of the disease course and living a sedentary lifestyle. Impairments due to an inactive lifestyle may be reversible with exercise. Additionally, exercise-induced anti-inflammatory effects may have potential in slowing the progression of the disease (Dalgas et al., 2008). Therefore, aerobic and resistance exercise training regimes have been implemented for this population. Among the many complications of MS, both peak ( $VO_{2\text{ peak}}$ ) and submaximal aerobic capacities are significantly impaired (Ponichtera-Mulcare, 1993). Oxygen consumption and aerobic endurance is reportedly lower among individuals with MS than predicted based on EDSS scores, further highlighting the importance of aerobic

training in this population (Kuspinar et al., 2010).

In order to evoke cardiovascular improvements, individuals with MS are recommended to exercise at a moderate intensity of 55-60% of  $\text{VO}_{2\text{ max}}$  (Dalgas et al., 2008). However, considering the full and/or partial paralysis caused by this disease, reaching this intensity may prove difficult. It has not yet been determined which piece of exercise equipment is ideal for aerobic training in individuals with MS in terms of exercise intensity and aerobic demands. An ideal piece of aerobic exercise equipment would allow these individuals to exercise at moderate to high intensities in order to evoke physiological changes.

There have been several attempts to identify appropriate exercise equipment to stimulate  $\text{VO}_2$  improvements. Arm ergometers have been used as a source of aerobic exercise, although findings have been inconsistent (Dalgas et al., 2008). Additionally, the combined voluntary arm-leg exercise via the NuStep machine has been used for moderate to high intensity exercise (as rated by the Borg scale) for individuals with severe cases of MS. This exercise demonstrated a strong trend to increase  $\text{VO}_{2\text{ peak}}$ , although the results were inconclusive due to the small sample size (Skerbaek, 2014).

A pilot study by Giesser and colleagues (2007) showed significant improvements in mobility following body-weight support treadmill training, although it was difficult to ascertain the level of aerobic demand that took place during this study. Likewise, functional electrical stimulation (FES) has been shown to improve walking speed and distance in individuals with MS (Barrett, Mann, Taylor, & Strike, 2009), although there is no evidence that FES exercise intensity is aerobic. Therefore, current research involving specific aerobic exercise machines, particularly FES exercise, is incomplete.

## **1.2 Objectives and hypothesis**

### *Objective 1:*

The primary objective of this study was to determine which piece of exercise equipment (from a selection of six common pieces) evokes the greatest aerobic demand when used at moderate intensity. This study examined FES-arm exercise (FES-A), FES-leg exercise (FES-L) and FES arm-leg exercise (FES-LA), voluntary arm crank ergometry, voluntary leg exercise (with body-weight supported treadmill training; BWSTT) and voluntary arm-leg exercise (with the NuStep machine). FES- arm exercise and FES-leg exercise was conducted on the RT300, and FES arm-leg exercise was conducted on the RT200 (Restorative therapies, Baltimore, MD)

### *Objective 2:*

As a secondary objective, we aimed to determine which piece of exercise equipment required the greatest aerobic demand ( $\text{VO}_{2\text{ peak}}$ ) when used at a maximal intensity. For this objective, we evaluated the voluntary arm-leg exercise with the NuStep machine and the FES-arm-leg exercise with the RT200. These two pieces of equipment were chosen as anecdotally they appear to be the most aerobically demanding.

### *Objective 3:*

As a tertiary objective, we aimed to determine if the addition of FES for any of the given exercises (arm ergometry vs. FES- arm exercise, NuStep vs. FES-arm and leg exercise, BWSTT vs. FES- leg exercise) adds significant aerobic demand when exercising at a perceived moderate workload.

*Objective 4:*

As a fourth objective, we aimed to determine which piece of exercise equipment individuals with MS prefer when exercising at a moderate intensity.

*Hypothesis 1:*

We hypothesized that voluntary arm-leg exercise on the NuStep and arm-leg FES exercise on the RT 200 would be the most aerobically demanding exercises when performed at a moderate intensity. The recumbent arm-leg cycle using the NuStep and arm-leg FES exercise using the RT200 recruit more major muscle groups during the exercise compared to the other four listed exercises. Therefore, it is expected that they are more aerobically demanding.

*Hypothesis 2:*

Further, we hypothesized that the added benefit of electrical stimulation will allow for a greater  $VO_{2\text{ peak}}$  on the RT200 when compared to the NuStep. We hypothesized this because the FES capability of the FES-AL enables the participant to contract the muscle groups involved in the exercise beyond volitional capacity. This would therefore evoke a greater aerobic demand.

*Hypothesis 3:*

We hypothesized that addition of FES-stimulation to a given exercise movement would increase aerobic demand during submaximal exercise. By matching exercise equipment in terms of movement, the addition of FES should produce a higher aerobic response,

which is consistent with having the muscles involved in the exercise being recruited beyond volitional capacity.

*Hypothesis 4:*

Finally, we hypothesized that there would be no difference in preferred piece of exercise equipment based on pain, safety, enjoyment, and adherence to exercise guidelines. This hypothesis is consistent with results found in a study by Pelletier and colleagues (2014) on exercise preference in a population with spinal cord injury.

## **Chapter 2: Review of Literature**

### **2.1 Overview of multiple sclerosis as a disease**

MS is an immune-mediated disease characterized by chronic inflammation of the central nervous system (CNS). The progressive decline in nerve function is attributed to the destruction of myelin around neurons (Tullman, 2013). Myelin is a key component of white matter, as it protects the nerve and accelerates nerve conduction (Simons & Lyons, 2013). This destruction of myelin occurs when immune cells such as pro-inflammatory Th cells, B cells, and macrophages target the myelin surrounding nerves, and produce pro-inflammatory cytokines, such as IL-2, IL-23, interferon  $\gamma$ , and tumor necrosis factor- $\alpha$ . These cytokines break down the myelin and myelin-producing cells called oligodendrocytes. Lesions are left in the areas damaged by immune cells and cytokines. Nerves in lesioned areas are susceptible to damage, which can impair or block nerve conduction. Although the structural damage is considered irreversible, improvements in nerve function are sometimes observed and attributed to decreases in inflammation, and the reorganization of sodium channels (Tullman, 2013). Such recovery is never full, and the persistent neural deficits result in functional symptoms such as decreases in strength, coordination, and sensation (Rietberg et al., 2011).

#### *2.1.1 Epidemiology of multiple sclerosis*

Canada has one of the highest incidence rates of MS worldwide, and this rate is increasing. A review conducted by Rosati (2001) reported Saskatoon, Saskatchewan as having the world's highest incidence rate, reaching 248 per 100 000 in the year 1999 (Hader, 1999). Currently in Ontario, there are approximately 25,000 individuals living with MS, with a prevalence of 204 cases per 100,000 and rising, which is consistent with

other Canadian provinces. Incidence rates increase directionally from the western seaboard of Canada to the eastern seaboard. The higher density of immigrants of French decent on the eastern boarder is a possible explanation of this prevalence gradient (Rosati, 2001), as the highest prevalence of MS worldwide is among European, American, and Australian continents (Ascherio & Munger, 2007).

### *2.1.2 Etiology of multiple sclerosis*

Currently, the cause of MS is unknown, however many risk factors have been identified (Tullman, 2013). Ethnicity is an important risk factor for the development of MS. Individuals that migrate from low risk countries (such as Asian decent countries) to high risk countries (such as Canada and the United Kingdom) are somewhat protected, and are less likely to develop MS. This protective effect is also transferable to the children of immigrants, however, these children are at greater risk of developing MS than their parents (Ascherio & Munger, 2007). This suggests alternative environmental risk factors independent of ethnicity. Latitude has been identified as a possible risk factor in the development of MS, as countries located further from the equator have reported higher prevalence rates. However, recently this latitude difference has been decreasing, as prevalence in southern regions has been increasing more rapidly than northern regions (Ascherio & Munger, 2007).

Historically, sex has played an important role as an MS risk factor. In Canada, there has been a consistent increase in female cases of MS over the last 50 years. From 1931-1935, the mean female: male ratio was approximately 1.9, whereas in 1980, this ratio was estimated at close to 3.2. The cause of this large increase in the ratio is

unknown, however proposed factors include a change in the typical child bearing age, more women in the work force and a change in the age of menarche (Orton et al., 2006).

### *2.1.3 Clinical course of multiple sclerosis*

MS is considered a long-term disease and the rate and severity of progression is dependent on its subtype. MS is categorized into progressive MS and relapsing MS. These are further divided into four subtypes: relapsing remitting MS (most common and least aggressive), secondary progressive MS, primary progressive MS, and progressive relapsing MS (most aggressive). These four categories are considered dynamic, as most individuals with relapsing remitting MS will progress to secondary progressive MS over time (Weiner & Stankiewicz, 2012).

Upon initial diagnosis, relapsing remitting MS is the most common type and accounts for 80% of all initial diagnoses (Ebers, 2006). Relapsing remitting MS (RRMS) follows a recognizable and consistent pattern, where the onset is characterized by sudden neurological impairment, which is called a relapse. From the point of onset, the person will experience an individualized pattern of relapses that occur at steady intervals. Over time, the frequency of relapses declines by an average of 0.4 relapses per year (Ebers, 2006), however, it is unknown how the frequency and severity of the relapses affects long term disability outcomes (Ebers, 2006). The decline in relapses contributes to disease transition from relapsing remitting MS to secondary progressive MS. This transition pattern is recognized in 80% of the MS population that is initially diagnosed with relapsing remitting MS (Ebers, 2006).

Secondary progressive MS is first diagnosed as RRMS, and later through disease progression turns into secondary progressive MS. It is characterized by the absence of



regular relapses, with continued steady disability occurring overtime (Goodin et al., 2002).

Primary progressive MS is a rare form of the disease where disability progressively worsens. Furthermore, the lesions associated with this type of MS predominantly affect the spinal cord. This form of MS is difficult to diagnose and may differ both immunologically and pathologically from relapsing remitting MS, although it is generally more severe symptomatically over time (Thompson et al., 1997).

Progressive relapsing MS is a form of the disease where progression overtime occurs in the form of both acute attacks and steady disability. Patients with progressive relapsing MS therefore experience relapses, however disability is not only attributed to these relapses (Goodin et al., 2002).

Declines in function are clinically assessed using the expanded disability status scale (EDSS). The EDSS is the successor to the original disability status scale, which was revised in order to detect smaller changes in function in the mid range of the scale. The EDSS rates disability on a scale of 0 (normal function) to 10 (death due to MS). However, the increments in which the scale increases are not constant, as half grades were incorporated as part of the revision (See appendix A) (Kurtzke, 1983). The EDSS can mark specific functional ability milestones. For example, an EDSS of 7 corresponds to an individual being confined to a wheelchair. The progression of MS can therefore be followed using the EDSS (Ebers, 2006).

The average life expectancy in individuals with MS is 5-7 years less than the general population (Ebers, 2006). MS generally progresses slowly over the course of 30-40 years. During this time, disability accumulates and becomes irreversible. For example,

the average time to developing an EDSS of 6 in relapsing remitting MS is 15 years (Ebers, 2006). Furthermore, approximately 50% of individuals with MS will require some form of ambulation aid within 10 years of diagnosis (Giesser et al., 2007). Therefore, medications and treatments are explored in order to prolong an individual's ambulatory lifestyle following diagnosis of MS.

In addition to physical disability, cognitive impairment is also common in individuals with MS. The prevalence of cognitive impairment ranges from 43% to 70%, with prevalence higher in later stages of the disease. The most common symptoms of cognitive impairment in individuals with MS are diminished long term memory, processing speed, and visual learning (Chiaravalloti & DeLuca, 2008).

#### *2.1.4 Treatments and therapies*

##### *2.1.4.1 Pharmacological treatments*

There is currently no cure for MS. However, treatments are available that aim to shorten the length of exacerbations, decrease the number of exacerbations, and provide relief of symptoms relating to relapses. A common drug therapy used in the treatment of acute relapses is a corticosteroid called prednisone (Goldenberg, 2012). The use of corticosteroids has been shown to decrease the length of time a relapse lasts, however it is not effective in preventing further disability. Therefore, all drug treatments recommended for individuals with MS are merely for symptom management. The usual course of corticosteroid treatment is a three-day intravenous protocol (Murray, 2006).

Beta-interferon is another form of drug therapy recommended for individuals with MS. This drug is predominantly recommended for individuals with RRMS as it has shown to reduce the incidence of relapse by 30%. These drugs are naturally occurring

cytokines with anti-inflammatory properties, and they have been shown to decrease the inflammation in MS lesions. However, this drug can have severe adverse side effects such as thyroid disease, decreased liver function, and leukopenia. Furthermore, it is still not associated with slowing disability progression (Goldenberg, 2012). Non-pharmacological options have been explored for people with MS given this limited efficacy for drug therapies.

#### *2.1.4.2 Non-pharmacological therapies*

Exercise rehabilitation may be an important treatment for MS, considering drug therapies have not been proven effective in the prevention of disease progression. A systematic review conducted by Sá (2014), examined randomized control trials regarding exercise and MS between the years 2004 to 2012. This review concluded that there are potential benefits in the prescription of rehabilitative exercise for those with MS. Additionally, a Cochrane systematic review was performed by Rietberg et al. (2011), which examined the effects of exercise on health related quality of life and activities of daily living in individuals with MS. This review was the first to isolate the effects of exercise therapy on these two variables, and it concluded that there was strong evidence supporting exercise as an effective treatment in regards to increasing muscle power and mobility activities for individuals with MS.

Furthermore, exercise is commonly used as a therapy for treating comorbidities of MS. Marrie and colleagues (2008) examined the prevalence of comorbidities in individuals with MS. It was found that hypercholesterolemia and hypertension were the most common comorbidities in this population. It is well known that a sedentary lifestyle is a risk factor for developing cardiovascular disease (Myers et al. 2007). Individuals with

MS are particularly susceptible to leading a sedentary lifestyle and therefore, integrating exercise into the lives of individuals with MS is also important for the prevention of morbidities common in sedentary individuals (Latimer- Cheung et al., 2013).

## **2.2 Exercise and multiple sclerosis**

### *2.2.1 Aerobic fitness*

Traditionally, exercise was not prescribed for individuals with MS as physicians seemed to agree that exercise would enhance acute fatigue symptoms. However, two studies conducted in the late 1990s (Petajan et al., 1996; Ponichtera-Mulcare et al., 1997) provided evidence to the contrary.

Ponichtera-Mulcare and colleagues (1997) explored the effects of exercise in two groups of individuals with MS. One group was ambulatory (EDSS 1.0-4.5) and the other was semi-ambulatory (EDSS 5.0-6.0). Both groups underwent a six-month training program, consisting of leg cycling ergometry three times per week for 30 minutes per day at 65-70% of maximum heart rate (as calculated by  $220 - \text{age}$ ). This study showed that it is safe for individuals with MS to exercise at a moderate intensity, and to perform  $\text{VO}_{2 \max}$  testing. Further, a trend for improved aerobic capacity of 19% in the ambulatory group and 7% in the semi-ambulatory group was found at the conclusion of the 24-week training study.

Petajan et al. (1996), used an exercise group and a non-exercise control group in individuals with MS. Both groups had a maximum disability EDSS score of six. Participants in the exercise group trained 40 minutes three times per week for 15 weeks using a cycle ergometer at 60% of  $\text{VO}_{2 \max}$ . A significant increase (pre: 24.2 l/min, post: 29.4 l/min,  $p < .05$ ) in  $\text{VO}_{2 \max}$  was found in the exercise group compared to no change

(pre: 26.0 l/min, post: 26.4 l/min,  $p < .05$ ) in the non-exercise control group. Furthermore, improvements in ambulation mobility, body care, and movement scores were noted. The evidence from these two studies suggests that cardiovascular exercise is potentially beneficial for individuals with MS. Furthermore, the improvements in aerobic capacity are similar to a non-MS control population (Petajan et al., 1996, Ponichtera-Mulcare et al., 1997).

Evidence regarding the benefits of aerobic fitness in the general population is well known. Some of these benefits include a decrease in the risk of cardiovascular disease, type II diabetes, osteoporosis, and depression (Mostert & Kesselring, 2002). These benefits of aerobic fitness have also been demonstrated in multiple special populations (Mostert & Kesselring, 2002). Therefore, it is now generally accepted that aerobic exercise will have the same beneficial effects on an MS population (Mostert & Kesselring, 2002).

In addition to these health benefits, aerobic exercise may be able to counteract symptoms unique to MS. Schmidt and Wonneberger (2014), studied the long-term effects of aerobic exercise on  $VO_{2\text{ peak}}$  and fatigue (as indicated by the fatigue severity scale score (FSS)). The participants were ambulatory and diagnosed with relapsing remitting MS. Each participant followed an individualized aerobic training program for 12 months. A subgroup analysis was performed in order to identify changes in  $VO_{2\text{ peak}}$  when fatigue was present (as indicated by an  $FSS > 4$ ), as well as when fatigue was absent ( $FSS < 4$ ). The findings showed improvements in  $VO_{2\text{ peak}}$  in both groups, however improvements in  $VO_{2\text{ peak}}$  when fatigue is absent plateaued at six months of training. In the subgroup where fatigue was present, there were improvements in  $VO_{2\text{ peak}}$  throughout the 12-month

training period. Further, there was a small but statistically significant decrease in fatigue levels following nine months of this exercise program ( $p < 0.03$ ). These findings demonstrate that aerobic exercise may be important in controlling fatigue symptoms in a population with relapsing remitting MS (Schmidt & Wonneberger, 2014).

In addition to the benefits it confers to MS symptoms, recent literature has reviewed the effects of exercise in preventing disease progression (Dalgas & Stenager, 2012). Although current clinical outcome measures of MS are not sensitive enough to provide definite conclusions, a recent review shows some evidence supporting exercise as an effective means of slowing disease progression (Dalgas & Stenager, 2012). For example, improvements in  $VO_{2\text{ peak}}$  have been positively correlated to disease-specific variables, such as improvements in walking performance and cognitive speed (Langeskov-Christensen et al., 2014). Additionally, there is evidence suggesting that  $VO_{2\text{ max}}$  improvements may prevent structural damage to the brain which is a result of disease progression (Langeskov-Christensen et al., 2014).

Nevertheless,  $VO_{2\text{ max}}$  has been found to be much lower in the MS population compared to the non-MS population (Kuspinar et al., Mayo, 2010; Langeskov-Christensen et al., 2014). Evidence shows that individuals with MS have a  $VO_{2\text{ peak}}$  which is in the 25<sup>th</sup> percentile compared to a healthy population (Kuspinar et al., 2010). An increase in EDSS score is an indicator of a decrease in  $VO_{2\text{ max}}$ , suggesting a negative correlation between disability status and  $VO_{2\text{ max}}$  in the MS population (Langeskov-Christensen et al., 2014).

### *2.2.1.1 Reliability and validity of VO<sub>2</sub> max in multiple sclerosis*

There is some debate as to whether VO<sub>2</sub> max or VO<sub>2</sub> peak is the appropriate terminology in the MS population. Recent research offers strong support that VO<sub>2</sub> max is the more correct term when conducting maximal effort aerobic testing for individuals with MS.

VO<sub>2</sub> max is defined as the maximum oxygen the whole body consumes during maximal exercise. Primary and secondary criteria are used to identify when an individual reaches their VO<sub>2</sub> max. The primary criterion for identifying VO<sub>2</sub> max is a plateau in oxygen consumption, despite an increase in workload. However, it is common for a healthy individual to be unable to reach this point in exercise. Further, it is likely that persons with MS will be unable to achieve this workload. Therefore, secondary criteria have been created, and include achieving a respiratory exchange ratio (RER) greater than 1.15, achieving calculated maximum heart rate (HR<sub>max</sub>), reaching 17 or higher on the Borg scale, and a high concentration of lactate in blood following exercise (Langeskov-Christensen et al., 2014).

Langeskov-Christensen and colleagues (2014) tested the validity of these criteria, as well as the reliability of the VO<sub>2</sub> max test specifically for individuals with MS. This study found that only 40% of persons with MS could achieve the primary criteria, whereas achievement of any of the secondary criteria measures ranged from 65-95%. Therefore, the secondary criteria may be more helpful when determining VO<sub>2</sub> max in the MS population. Considering the low achievement of the primary criteria, VO<sub>2</sub> max is often referred to as VO<sub>2</sub> peak for this population (Langeskov-Christensen et al., 2014). Furthermore, particular secondary criteria have been found to be more valid than others

in persons with MS. The achievement of  $HR_{max}$  may not be an ideal criteria for  $VO_{2\ max}$  testing for those with MS, as previous work has shown only 65% of this population were able to achieve age-predicted max heart rate (HR) (Langeskov-Christensen et al., 2014). Further, medications (such as beta blockers), which are common in this population, may affect  $HR_{max}$ . Rate of perceived exertion (RPE) is a measure of exercise intensity where the participant uses a scale to identify how hard they are working. The attainment of a RPE that was greater than 17 on the Borg's 6-20 scale, as well as a respiratory exchange ratio greater than 1.15 were found to be the best indicators of  $VO_{2\ max}$ , as 95% and 90% respectively of an MS sample were able to achieve this criteria.

The test-retest reliability of  $VO_{2\ max}$  has also been studied in those with MS.  $VO_{2\ max}$  was found to be a reliable measure of fitness, however to account for day-to-day differences in  $VO_{2\ max}$ , a minimum change in  $VO_{2\ max}$  of 11% must be made to be considered a meaningful cardiovascular improvement (Langeskov-Christensen et al., 2014).

#### *2.2.1.2 Aerobic exercise prescription for individuals with Multiple Sclerosis*

Currently, exercise is prescribed to individuals with MS but guidelines regarding dose, duration, and type are only recently emerging. The first exercise guideline review was created by Dalgas and colleagues (2008). This review aimed to make endurance and resistance exercise training guidelines that were easily accessed and understandable for clinical use. For endurance exercise, the guideline suggests exercising 2-3 times per week, for 10-40 minutes at 50-70% of  $VO_{2\ max}$ . Further, it is suggested that progression should be in the form of increasing volume and frequency. The exercise modalities suggested in this review were divided based on ambulatory ability. For individuals who



are less ambulatory, arm-ergometry, leg-ergometry, arm-leg ergometry, and treadmill walking were suggested. For individuals who are more ambulatory, aquatic exercise, rowing, road biking, and running were suggested. However, a limitation noted in this guideline is that it is not known what modality is optimal for eliciting an aerobic response.

Following this review, the American College of Sports Medicine (ACSM) developed evidence-based exercise guidelines for individuals with MS (Latimer-Cheung et al., 2013). This guideline is based on performing the minimum required exercise in order to achieve “important health benefits.” Similar to the Dalgas et al. (2008) guideline, recommendations are suggested for both endurance and resistance exercise. Further, these guidelines are applicable to individuals who have mild to moderate MS, as indicated on the EDSS of a score 0-8. The endurance component of these exercise guidelines suggests a minimum of 30 minutes of endurance exercise, at a moderate intensity no less than two times per week. A moderate intensity is indicated by a score of 6 on the 10-point RPE scale. Further, this guideline provides similar activity modality suggestions to that in the Dalgas et al. (2008) guidelines, but it remains unclear which modality is recommended for achieving optimal exercise for the MS population.

#### *2.2.1.5 Modalities of aerobic exercise*

More research is needed on the aerobic demand of various modalities of aerobic exercise that can be used in the MS population. This information is necessary to further develop the current MS exercise guidelines (Latimer-Cheung et al., 2013). There are some aerobic exercise modalities that are common among other populations with neurological impairment. These modalities may be able to be transferred to the MS

population, however these pieces of equipment have not yet been examined.

Furthermore, aerobic exercise involving functional electrical stimulation (FES) is common among persons with neurological impairment (Peng et al., 2011). Thus, the following exercise modalities have been identified for populations with neurological impairment.

*i) Traditional aerobic exercise modalities*

There are many types of exercise that provide an aerobic stimulus, however for the purpose of this review, rehabilitative exercise modalities, which can be used by a wide range of disability severities have been included. Three types of exercise that have been used in persons with MS are arm ergometry, recumbent arm-leg exercise (NuStep), treadmill training and body weight supported treadmill training (BWSTT).

There is a paucity of research involving aerobic training on recumbent arm-leg exercises. In an aerobic exercise feasibility study by Skjerbæk et al. (2014), recumbent arm-leg was one type of exercise used when creating individualized exercise programs for individuals with severe MS. Participants were randomized in to a control or exercise group. The exercise group participated in ten exercise sessions as part of a four-week inpatient rehabilitation program involving endurance arm-leg exercise using the NuStep machine. Exercise sessions involved interval training at 65%-75% of  $\text{VO}_{2\text{ peak}}$ . Results showed that there was a trend toward a group\*time interaction for  $\text{VO}_{2\text{ peak}}$  improvements in the exercise group ( $p=.06$ ). However, as other forms of exercise training were also used in this study, the specific aerobic effects of recumbent arm-leg exercise are not known.

Treadmill training is a common form of exercise after a stroke, but is not yet well-studied in persons with MS (Van den Berg et al., 2006). A pilot study by Van den berg and colleagues (2006) tested the effects of treadmill training on fatigability and walking performance in persons with MS. Participants exercised on a treadmill three times per week for four weeks. Training intensity was progressed by increasing exercise duration to a maximum of 30 minutes. Speed was also increased, with the goal of achieving 55-85% of  $HR_{max}$ . Following four weeks of training, there was a significant improvement in walking ability but no changes in fatigue. Aerobic demand was not measured in this study; therefore the aerobic demand of this exercise is unknown in this population. This suggests treadmill training is feasible for persons with MS and may be a good mode of aerobic exercise, however its effectiveness as an aerobic stimulus is not fully understood (Van den Berg et al., 2006).

A study by Pilutti and colleagues (2011) assessed the effect of BWSTT on functional ability, fatigue, and quality of life in people with primary progressive MS. Participants in this study trained for 30 minutes, three times per week for 12 weeks. Training was progressed by increasing the speed of the treadmill and subsequently decreasing body weight support. Following the exercise training protocol, results showed that following training participants remained stable in functional ability and improved in quality of life (QOL) outcome measures. However, there was no significant affect on fatigue. Progression of training intensity and improvements on QOL outcome measures may indicate that BWSTT is a suitable exercise for the MS population. However, there are currently no studies that examine the effects of BWSTT on aerobic capacity in the MS population.

Arm ergometry is a common exercise among populations with neurological impairment (Hicks et al., 2003; Mostert & Kesselring, 2002; Skjerbæk et al., 2014). Furthermore, the current exercise prescription guidelines for persons with MS suggests arm ergometry as an effective mode of aerobic exercise (Dalgas et al., 2008; Latimer-Cheung et al., 2013). Whether or not this is the optimal mode of exercise for aerobic gains in individuals with MS is unknown, and it is important to compare its value against other forms of exercise. Some research has shown aerobic and functional benefits in the MS-population, however the actual aerobic demands of each exercise modality are unknown.

*ii) Functional electrical stimulation (FES) exercise*

FES is an emerging form of exercise for individuals with MS. Chang and colleagues (2011), studied the feasibility of FES exercise, and its effects on muscular strength and fatigability in individuals with MS. Traditionally, it was felt that traditional voluntary exercise may be contraindicated for individuals with MS, because of the potential for the severe and debilitating fatigue that would result from challenging the central nervous system (CNS). Therefore, exercise that bypasses the CNS may be beneficial as a means of preventing this exercise-induced fatigue. FES exercise challenges the peripheral nervous system (PNS), while bypassing the CNS, and therefore it may be an ideal exercise modality for the MS population (Chang et al., 2011). In a study by Chang and colleagues (2011), individuals with MS in this study participated in an isometric knee extension FES training program. In this program, stimulation was applied to the quadriceps in order to facilitate knee extension. Participants exercised in a chair that held the knee fixed at a 90° angle in order to elicit isometric contractions using

FES. This training was performed at home three days per week for 30 minutes per day for eight weeks. Fatigue was measured using the Modified Fatigue Impact Scale (MFIS). Further, the generalized estimating equations model was then used to identify the contribution of both central and peripheral fatigue to general fatigue. The study by Chang and colleagues (2011) showed that FES exercise is in fact feasible in persons with mild to moderate MS (EDSS 1.0-4.0). Furthermore, results showed that fatigue related to the CNS was rated higher than fatigue related to the PNS. Following this eight-week training program, there was an increase in fatigue resistance in the quadriceps, and this was attributed to improvement in fatigue resistance related to the CNS using general estimating equations. However, more research is necessary to determine the aerobic demands of FES exercise on persons with MS (Chang et al., 2011).

The cardiovascular effects of FES exercise have yet to be determined in persons with MS but have been widely studied in other populations with neurological impairment, such as spinal cord injury (SCI), cerebral palsy, and stroke. In individuals with SCI, there is evidence that FES exercise training can elicit enough of a cardiovascular response to increase  $VO_{2\text{ peak}}$ , capillary density, cross sectional area of arteries, blood inflow volume, and cardiac output (Peng et al., 2011), including a 20-35% increase in peak oxygen uptake following 12-26 weeks of FES-cycling exercise training. Furthermore, the oxygen demand associated with this exercise is equivalent to the oxygen demand of walking in the able-bodied (Peng et al., 2011). These aerobic benefits may also be realized in a MS population, and highlight the importance of including FES exercise training as a modality of exercise for persons with MS.

There are many modes of FES exercise, such as FES arm cycling, leg cycling, and elliptical ergometry. FES leg cycling is commonly used, and FES arm-leg ergometry is an emerging piece of exercise equipment. Both pieces of equipment stimulate the legs using the quadriceps, hamstring, and gluteal muscles. However, the FES-elliptical trainer moves the legs through a seated-stride pattern, compared to the cyclic pattern of the FES leg cycle. A study by Hamzaid and colleagues (2012) compared the aerobic effects of leg cycling exercise to leg elliptical exercise in individuals with SCI. The  $\text{VO}_2$  peak,  $\text{VCO}_2$  peak and VE were greater on the elliptical trainer than the leg cycle. Additionally, force generated using the elliptical trainer was twice that achieved on the cycle, suggesting possible strength training implications. Stimulation using both the arms and legs during elliptical FES exercise has not yet been examined. However, a new piece of technology developed by Restorative Therapies Innovations (Baltimore, MA) enables an individual to exercise while simultaneously stimulating the arms and legs. This equipment (RT200) has not yet been tested on persons with MS, however given the aerobic benefit seen in the SCI population it may be an ideal piece of exercise equipment to use for aerobic exercise in individuals with MS. No research to date has examined the aerobic demand of FES arm ergometry.

#### *2.2.1.4 RPE for individuals with MS*

Exercise intensity in persons with MS is commonly estimated using an RPE scale. One common scale is the Borg 6-20 RPE (Borg, 1990). Use of an RPE scale has been shown to be a valid indicator of exercise intensity for both disabled and able-bodied populations (Morrison et al., 2008). Further, in a population with MS, using an RPE scale may be a better indicator of exertion compared to other common criteria (i.e. HR)

(Morrison et al., 2008). A study by Anema et al. (1991) reported that in a sample of persons with MS, 53% had evidence of cardiovascular autonomic dysfunction, and 28% of these participants also had an abnormal HR response to standing. Therefore, HR may not be an accurate measure of exertion during exercise in this population. Currently, RPE has been included in the MS exercise guidelines for estimating intensity during endurance exercise (Latimer-Cheung et al., 2013), and it has been used in studies involving aerobic exercise for individuals with MS (White et al., 2000).

### **2.3 Exercise preference and adherence**

A meta-analysis by McAuley and colleagues (2007) showed that people with MS participate less in physical activity programs than able-bodied individuals. This may be particularly alarming considering exercise has been shown to effectively treat symptoms of MS (McAuley et al., 2007). Therefore, it is important to identify what aerobic exercise is preferred amongst persons with MS in order to prevent withdrawing from an exercise program. Furthermore, self-efficacy has been associated with exercise adherence (McAuley et al., 2007), and thus identifying equipment this population enjoys and is confident using may affect exercise adherence.

In able-bodied persons, preference to a type of exercise has been correlated to motivation and exercise adherence (Daley & Maynard, 2003). An exercise preference questionnaire was developed by Pelletier and colleagues (2014) in order to determine what exercise equipment people with spinal cord injury preferred using. This questionnaire included four sections: pain, safety, enjoyment, and adherence to spinal cord injury exercise guidelines. Participants were asked to rate each piece of equipment used in the study with this questionnaire. The aerobic exercise equipment used included an arm

ergometer, arm glider, arm leg recumbent stepper, and arm leg cycle ergometry. The results from this study indicated that there were no differences in perceived enjoyment using the various types of aerobic exercise equipment. However, perceived safety was lower on the arm leg recumbent stepper compared to the other three pieces of exercise equipment. With this considered, they determined that promoting the use of arm only exercise for individuals with SCI may be ideal as it appeals to a broader spectrum of abilities for the same enjoyment.

A study by Pilutti and colleagues (2016) assessed exercise preference on the arm and leg recumbent stepper, as well as the body weight support treadmill trainer (BWSTT). It was found that after 12-weeks of exercise, the arm and leg recumbent stepper was preferred among individuals with MS. This is currently one of the only studies examining exercise preference in individuals with MS. In order to improve exercise adherence in people with MS, it is important to identify what exercise equipment is preferred.



## **Chapter 3: Methods**

### **3.1 Participants**

Ten participants were included in the study. Ages ranged from 42-65 years of age. Participants were recruited from the Power Cord Exercise Program at Brock University, as well as the MS Society Niagara community. All participants recruited had some ability to walk, as indicated by an EDSS score of 7 or lower.

#### *3.1.1 Inclusion criteria*

To be eligible for inclusion into this study, participants required a diagnosis of MS obtained at least one-year prior to enrollment, general medical stability, be between the ages of 18-75 years, and have a self-reported EDSS score between 3 and 7. The full EDSS scale can be found in Appendix A, however, in brief an EDSS score of 3 indicates “moderate disability in one functional system, or mild disability in three or four functional systems, with no impairment to walking,” while an EDSS score of 7 indicates “unable to walk beyond approximately 5m even with aid. Essentially restricted to wheelchair; though wheels self in standard wheelchair and transfers alone. Up and about in wheelchair some 12 hours a day.” Potential participants were excluded from the study if they were non-ambulatory (EDSS score >8), and/or had a history of cardiovascular disease or hypertension. All participants were medically approved for exercise prior to enrollment, and the Brock University Biosciences Research Ethics Board (REB-14-177-DITOR) approved this study. Participant characteristics are available in Table 1.

## **3.2 Procedures**

Researchers were fully trained in CPR and First Aid level C, and in the case of testing with the RT-200, RT-600 and RT-300, the researchers were Functional Electrical Stimulation Course Certified (Restorative Therapies, Baltimore, MA). The testing involved an orientation, followed by three phases of testing: the familiarization phase, the submaximal exercise testing, and maximal exercise testing. The familiarization phase involved six sessions, whereby within each session the participant was familiarized with one piece of exercise equipment. These sessions were scheduled with a minimum of 24 hours between sessions. The submaximal exercise-testing phase involved six testing sessions where the participant exercised at a predetermined moderate intensity on one piece of exercise equipment each session. These testing sessions were separated by a minimum of 48 hours to ensure fatigue from the previous testing session would not affect the testing session on the subsequent day. The third phase involved maximal testing on the FES arm leg exercise, and the NuStep exercise machine. These maximal testing sessions were separated by a minimum of one week in order to ensure full recovery from the previous maximal exercise testing session. All exercise testing was randomized by piece of equipment used. Day-to-day differences in MS symptoms were accounted for prior to beginning any exercise session. If the participant reported an exacerbation of any symptom common to MS (i.e. increased fatigue, pain, or spasticity) the testing session was rescheduled.

### *3.2.1 Orientation*

Prior to any data collection, participants were first shown all the exercise equipment including Restorative Therapies FES cycle ergometers (FES RT-200, FES RT-

300A, and FES RT-300L), BWSTT, arm ergometry, and the NuStep. Furthermore, they were shown the metabolic cart and the aerobic testing procedures were explained. At this time, all questions were answered and the participants were asked to read and sign the consent form. Participants were informed of their right to withdraw from the study at anytime without penalty.

### *3.2.2 Familiarization testing*

Prior to any aerobic testing, all participants completed one familiarization session for each of the six pieces of exercise equipment. At this time, the participants were also asked which pieces of equipment being used in the study they had previously used. The process included an instructional briefing relevant to the equipment, followed by a body weight transfer onto the equipment if required. Participants were asked to begin with a warm-up by exercising at a low intensity to practice proper technique. The purpose of this familiarization session was to determine the settings required to elicit a perceived moderate intensity exercise for each participant. These settings were then recorded and used for subsequent testing.

If the exercise involved FES, the stimulation parameters were set at the beginning of the exercise session. After the five-minute warm-up, the machine transitioned to a ramp-up phase where stimulation intensity (mA) was increased at a rate of 0.5% per second until the maximum amplitude was reached. Pulse width and pulse frequency were set to 250ms, and 40.0Hz for all participants, unless tetanic contraction could not be achieved by only increasing pulse amplitude. In this case, pulse width was reduced, and pulse frequency was increased in order to make the sensation of the stimulation more comfortable for the participant. During active transition (ramp-up phase), the researcher

monitored muscle contractions on the muscles that were stimulated. Ideally, stimulation was increased until these muscles reached a tetanic contraction.

In order to familiarize each participant with the 6-20 Borg Scale, participants were asked to incrementally increase the intensity up to 13 points (See appendix B). Ratings of perceived exertion were determined peripherally, centrally and overall. To determine peripheral RPE participants were asked, “How hard are your arms and/or legs working?” To determine central RPE participants were asked, “How hard are you breathing?” To determine overall RPE participants were asked, “How hard are you working overall?” All 3 questions were asked to the participant in order to try to ensure the overall RPE was as close to 13 as possible, without exceeding a moderate intensity. Once the participant reached an overall RPE between 11-13 on the overall RPE, the machine settings (resistance as well as stimulation parameters when using the FES-exercise equipment) were recorded and used for subsequent testing sessions. The sessions ended with a quick debriefing and reiteration of testing protocols set to take place in the next phase of testing. Any questions the participant had about the testing were also answered during the familiarization sessions.

### *3.2.3 Aerobic demands of each exercise*

#### *3.2.3.1 General testing procedures*

Each participant performed one moderate intensity exercise test on each piece of equipment. In addition, each participant performed a maximal intensity exercise test on the RT200 (arm-leg-FES exercise) and the NuStep (voluntary arm-leg exercise).  $\text{VO}_2$  was determined during all moderate and maximal exercise tests. There was at least 24 hours of rest between each moderate exercise test and at least one week of rest between

maximal exercise tests. Height and weight were collected using a beam weighing scale before the first testing day.

If necessary, the participant was provided assistance to transfer onto the exercise machine. The participant was then asked to fasten the gas exchange mask over his or her nose and mouth, for the purpose of collecting expired gases. The metabolic analyzer was then calibrated while the participant was still at rest in their seat. In the case of FES-exercise, adhesive electrodes were placed on the quadriceps, hamstring, and gluteal muscles for lower limb stimulation. For stimulation on the upper limbs (during RT-200 exercise) adhesive electrodes were placed on the biceps, triceps, and posterior deltoid muscles. Once the electrodes were applied, the FES parameters were set to the comfortable moderate intensity levels pre-determined in the familiarization testing. For individualized set-up on the exercise equipment, see section 3.2.4.

#### *3.2.3.2 Moderate exercise testing*

The exercise session began by fitting the participant with a mask from the metabolic cart used to collect gas exchange. The exercise equipment used during this session was then adjusted for each participant (to accommodate leg length, arm length, etc.). The participant began with a five-minute warm-up on the selected piece of exercise equipment. Following the five minute warm-up, the exercise machine was set to produce the same intensity used during the familiarization period to elicit a moderate RPE. Following one minute of exercise at this preset RPE, the participant was asked to rate his or her exertion as it pertained their arms and/or legs, breathing and overall exertion based on the three questions mentioned previously. Machine settings were then adjusted to ensure that the participant was exercising at an RPE score of 11-13 on one or more of the

given criteria. The goal of this was for the participant to maintain a self-selected moderate intensity on each piece of equipment (corresponding to a 11-13 on the Borg scale) for 10 minutes. The average  $\text{VO}_2$  over the final two minutes of exercise was recorded as the aerobic demand for that piece of equipment. There was a five-minute cool down phase following the exercise test, where participants performed exercise against no resistance, and in the case of FES-exercise, with no stimulation (just passive exercise as provided by the motor of the machine). After cool down, the participants removed the gas exchange mask and were transferred back into their wheelchair (if applicable). Upon completion of each session, the participants were asked to fill out the exercise preference questionnaire developed by Pelletier and colleagues (2014) for the piece of exercise equipment they used that day (Pelletier et al., 2014; see Appendix C). This questionnaire was intended for use by a population with SCI, however it can be analyzed for a sample with MS by referring to the MS Canadian society of exercise physiology (CSEP) and MS society of Canada exercise guidelines.

These testing sessions were performed on six different pieces of exercise equipment. Thus, the tests were performed on six separate days, separated by at least 24 hours.

#### *3.2.3.3 Peak exercise testing*

A  $\text{VO}_{2\text{ peak}}$  test was performed on the NuStep and RT-200 exercise machines. For  $\text{VO}_{2\text{ peak}}$  testing, participants warmed up at a very light intensity for five minutes. Resistance was then incrementally increased (as described earlier) to elicit a maximal exercise until i) volitional fatigue, which was defined by a decrease in speed of 10 units for longer than five seconds, or ii) the participant reached an RER of 1.1, or iii) the

maximum resistance was achieved.  $\text{VO}_2$  was measured throughout the test and the  $\text{VO}_2$  during the final 30 seconds of the test was recorded as the  $\text{VO}_{2\text{ peak}}$ . Once completing a  $\text{VO}_{2\text{ peak}}$  test, the participant did not have another testing session until one week following that session.

#### *3.2.4 Exercise protocol for each piece of equipment*

##### *3.2.4.1 Body weight supported treadmill training (BWSTT)*

BWSTT was performed using the Loko S 2000 (Woodway, Germany) under the supervision of no less than three volunteers for safety, with at least one being the student principal investigator. A harness was fastened along the participant's waist, and the participant was slowly hoisted up to a standing position over the treadmill using cables. Once the participant was upright, the mask from the metabolic cart was fitted. The appropriate amount of body-weight support was determined in the familiarization session so that feet were flat on the treadmill, without buckling at the knees. The amount of body-weight support remained consistent throughout the testing session. Once the body weight support was set, the treadmill was turned on, and one volunteer on each side of the treadmill assisted the leg movement through the gait cycle.

During submaximal BWSTT, intensity was incrementally increased by increasing the speed of the treadmill by 0.5m/s every minute until the overall RPE reached 11-13.  $\text{VO}_2$  was collected for the duration of the exercise.

#### *3.2.4.2 Arm ergometry*

An Arm ergometer (model 881E, Monark Exercise AB, Poland) was performed from a seated position, either in a chair provided or from the participant's own wheelchair. The participants were fitted with the gas exchange mask prior to beginning the exercise. The participants' hands were secured to the handles with tensor bandages if necessary. Participants cycled at 50 revolutions per minute, which was indicated on the arm ergometer digital screen.

During arm ergometry, exercise intensity was incrementally increased by raising the resistance by 5 watts per minute (Pelletier et al., 2014). The resistance was adjusted on the arm ergometer by tightening a dial on the front of the equipment until the Watts measurement moved 5 units higher every minute until the participant scored an overall RPE of 11-13. The cadence was kept constant at 50 revolutions per minute throughout the testing.  $\text{VO}_2$  was measured throughout the duration of the exercise.

#### *3.2.4.3 NuStep*

The NuStep (model T5, Nustep, Ann Arbor, MI) exercise included a participant transfer onto an adjustable seat, securing the feet with straps, and adjusting specific settings to the participant based on height and arm length. The participant was asked to maintain the speed identified as a moderate intensity during the familiarization session.

During NuStep recumbent stepping exercise, intensity was incrementally increased by raising the resistance of the machine by 1 unit per minute (the machine has built-in resistance levels ranging from 0-15). The cadence was kept constant at 100 steps per minute throughout the testing. For submaximal testing, the intensity (resistance) was increased every minute until the participant scored a RPE of 11-13. At this point,  $\text{VO}_2$



was recorded. For maximal testing, the intensity was increased by one unit every minute until one of the following criteria was reached: i) RER reached 1.13, ii) the participant gave up from exhaustion, or iii) the participant could no longer maintain a speed of 100 steps per minute. At this point maximal  $\text{VO}_2$  was recorded as  $\text{VO}_{2\text{ peak}}$  for this exercise.

#### *3.2.4.4 RT300, FES-L and FES-A exercise*

Electrodes were applied to the quadriceps, hamstrings, and gluteal muscles during FES leg cycling (FES-L), or to the biceps, triceps, and posterior deltoid during FES arm cycling (FES-A). The participant then had their wheelchair fastened to the exercise machine, or were asked to sit in a chair and place their feet on the pedals, and the gas exchange mask was fitted to the participant.

During RT300 exercise, intensity was incrementally increased by raising the resistance of the machine by one Nm per minute. The cadence and stimulation parameters (amplitude, pulse width and frequency) were kept constant throughout the testing, as determined during the familiarization session. The cadence was kept constant at 50 revolutions per minute throughout the testing.

#### *3.2.4.5 RT200, FES-LA exercise*

Electrodes were applied to the quadriceps, hamstrings, gluteal, biceps, triceps, and posterior deltoid muscles. The participant then transferred on the exercise seat if required, and feet and arms were fastened to the pedals if necessary, and the gas exchange mask was fitted to the participant. Then, the RT-200 was turned on and set to the speed determined in the familiarization session.

During RT200 submaximal exercise, intensity was incrementally increased by raising the resistance of the machine by one Nm per minute. The stimulation parameters (amplitude, pulse width and frequency) were kept constant throughout the testing as determined during the familiarization session. The cadence was kept constant at 50 revolutions per minute throughout the testing. For maximal testing, the intensity was incrementally increased by 1.0 Nm every minute until one of the following criteria was reached: i) RER reached 1.13, ii) the participant gave up from exhaustion, or iii) the participant could no longer maintain a speed of 50 revolutions per minute. At this point maximal  $\text{VO}_2$  was recorded as  $\text{VO}_{2\text{ peak}}$  for this exercise.

### **3.3 Outcome measures**

#### *3.3.1 Steady- state submaximal $\text{VO}_2$*

$\text{VO}_2$  relative to body mass was recorded using a VacuMed Vista Mini CPX made by VacuMed (Ventura, California) metabolic analyzer. This analyzer collected a sample of air from a mask the participant wore during exercise testing. This air sample was analyzed by the Vista Mini CPX, and  $\text{VO}_2$  data was collected. A plateau in oxygen consumption during moderate exercise testing identified submaximal  $\text{VO}_2$ . The mean of the last five data points of the relative  $\text{VO}_2$  was calculated. One data point during  $\text{VO}_2$  collected was the average  $\text{VO}_2$  collected over a 20 second time period. Therefore, the submaximal  $\text{VO}_2$  was an average  $\text{VO}_2$  calculated from 120 seconds of exercise. This number was recorded as the submaximal  $\text{VO}_2$  for the participant on that specific exercise.

#### *3.3.2 $\text{VO}_{2\text{ peak}}$*

VO<sub>2</sub> peak relative to body mass was recorded using the metabolic analyzer. This outcome measure was used for the NuStep and RT200 machines during the maximal exercise testing sessions. VO<sub>2 peak</sub> was defined as the maximum oxygen consumption relative to body weight achieved during the maximal exercise test. VO<sub>2</sub> peak was recorded as the maximal point on the graph achieved during the test. Each point of data represented an average VO<sub>2</sub> taken over a 20 second time period.

### *3.3.3 RPE*

The Borg 6-20 scale was used to identify moderate exercise intensity. Moderate exercise intensity was defined as a 13 on the scale. Once the participant reached an overall RPE of 11-13 during an intensity measure, this value was recorded.

### *3.3.4 Exercise preference*

The exercise preference questionnaire used in this study was developed for SCI by Pelletier and colleagues (2014) (Appendix C). This questionnaire can be used with no changes for a sample with MS, however in analysis the MS exercise guidelines will be discussed instead of the SCI exercise guidelines. This questionnaire was separated into four components: pain, safety, enjoyment, and adherence to exercise guidelines. Three questions were asked about pain on this questionnaire. The participants rated pain on a scale of 1 to 7, where 7 was extreme pain and 1 was no pain at all. These scores were summed and a higher score indicated more pain. Two questions were asked about safety. The participants rated safety on a scale of 1 to 7, where 7 indicated competency and feelings of safety and 1 indicated no competency or feelings of safety using the equipment

independently. The scores on these questions were summed, and a higher score indicated higher feelings of safety while using the equipment. Enjoyment was rated on a scale of 1 to 7, where 7 indicated full enjoyment and 1 indicated no enjoyment. Two questions were asked regarding adherence to MS exercise guidelines. The participants indicated how frequently they could expect using the exercise equipment per week, and this number was compared to the current exercise guidelines for MS, and this was similarly done for exercise duration.

### **3.4 Statistical Analysis**

Statistical analysis was performed using Microsoft Office Excel 2010, and SPSS version 20. Significant p-values were determined at  $p < .05$ . The confidence interval used was 95%.

#### *3.4.1 Steady-state submaximal $VO_2$*

The mean value of the last 5-data points collected during this exercise test was used in analysis. Each data point represents a mean value of oxygen consumption during 20 seconds of exercise. Variability was represented using standard deviation. A one-way, repeated measures ANOVA was used to analyze these means from each piece of exercise equipment, with a confidence interval of 95%. Following a significant p-value, a Bonferroni correction post-hoc test was used to compare means.

#### *3.4.2 $VO_2$ peak*

The maximum oxygen consumption data point collected during the exercise tests was used as the  $VO_2$  peak value in analysis. This data point is representative of a mean

oxygen consumption value from 20 seconds of exercise. A dependent samples t-test was used to determine significance using a p-value.

#### *3.4.3 FES vs. Non-FES*

The mean oxygen consumption values collected during the submaximal VO<sub>2</sub> testing are used in this analysis. The traditional non-FES equipment used in this study was matched for the FES version of the similar or identical exercise equipment. Variability was represented using standard deviation. A dependent samples t-test was performed on the means from the above submaximal test to determine the p-value. This test was performed on three comparisons: the FES-A and arm ergometer, the FES-L and the BWSTT, and the RT200 and the NuStep.

#### *3.4.3 Exercise preference*

The questionnaire was divided in to five sections prior to analysis: pain, safety, enjoyment, exercise frequency, and exercise duration. For pain, safety, and enjoyment, the questionnaire was scored for each piece of equipment, and the mean value was used in analysis. Variability was represented using the standard deviation. A one-way, repeated measures ANOVA was performed on the means of these sections in order to determine significance using the p-value. If a significant p-value was found, then pairwise comparisons were performed using a Bonferroni post-hoc test. For exercise frequency and duration, the questionnaires were scored, and the average value was used in analysis. The average scores determined from these sections were then compared to the CSEP and MS society exercise guideline to determine whether participants would use these selected pieces of equipment in adherence to the current guidelines.

## Chapter 4: Results

### 4.1 Exercise testing adherence

Twelve participants were recruited for this study. Two participants were dropped from the study due to attendance issues, and one participant was excluded from VO<sub>2</sub> peak testing due to the inability to complete the maximal testing session subsequent to health problems related to changes in pharmacological treatment, however this participant was included in all other analyses. Therefore, a total of ten participants met the study requirements and comprise the final data.

### 4.2 Submaximal testing measures

One-way, repeated measures ANOVA determined that there was a significant main effect in mean submaximal VO<sub>2</sub> (ml•kg•min<sup>-1</sup>) between the six selected pieces of exercise equipment ( $F(5,45) = 8.8, p = 0.00$ ). Variances of the differences between all possible pairs of groups were equal, and the assumption of sphericity was upheld ( $\chi^2(14) = 0.5, \eta^2 = 0.5, p > 0.005$ , see Figure 1). A Bonferroni post-hoc test was performed, and revealed three significant differences between equipment. The arm ergometer was significantly less aerobically demanding than the NuStep, BWSTT and FES-LA ( $9.54 \pm 0.7$  ml•kg•min<sup>-1</sup> compared to  $14.6 \pm 1.3$  ml•kg•min<sup>-1</sup>,  $p = .01$ ;  $13.4 \pm 0.7$  ml•kg•min<sup>-1</sup>,  $p = .031$ ;  $13.8 \pm 1.2$  ml•kg•min<sup>-1</sup>,  $p = .03$  respectively; see Table 2).

There was no analysis performed on the central and peripheral scores, as data was inconsistently reported with the participants due to challenges answering the questions and continuing with the exercise. Therefore, it was decided to leave these RPE scores out

of data analysis. A one-way ANOVA determined a significant main effect between the overall RPE of exercise equipment ( $p = 0.014$ ), however a Bonferroni post-hoc test revealed no significant differences. Therefore, RPE was consistent between exercise modalities (Table 4).

#### **4.3 $\text{VO}_{2\text{ peak}}$ testing measures**

Not every participant reached the requirements of a  $\text{VO}_{2\text{ max}}$  test, even with the secondary criteria. Only 1 participant out of the 9 included in analysis reached an RER of 1.1. Therefore, this test was measured as a  $\text{VO}_{2\text{ peak}}$ , not a  $\text{VO}_{2\text{ max}}$  test.

A dependent samples t-test was performed to determine whether the NuStep or RT 200 exercise was more aerobically demanding when tested at a maximal capacity. No significant difference was found between these two pieces of equipment ( $19.2 \pm 1.0 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$  vs.  $18.0 \pm 1.1 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ ,  $p = 0.97$ ), respectively. A sub-analysis was performed on the participants with an EDSS of 6.0 or higher. A dependent samples t-test on this sample ( $n=5$ ) showed a trend for a significant difference (NuStep;  $17.5 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1} \pm 2.5$  vs. FES-LA;  $16.8 \pm 2.3 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ ,  $p = 0.07$ ), however no significant difference was found between the NuStep and the RT-200 exercise.

#### **4.4 Comparing non-FES to FES exercise**

Exercise equipment used in this study was paired based on exercise movement. The arm ergometer was compared to the functional electrical stimulation arm exercise (FES-A), the NuStep was compared to the FES-LA, and the BWSTT was compared to the functional electrical stimulation leg exercise (FES-L). A dependent samples t-test was

performed on each of these pairs. No significant differences were found between the arm ergometer and FES-A exercise ( $p=0.8$ ). No significant difference was found between the NuStep and FES-AL ( $p=0.2$ ), as well as the BWSTT and FES-L ( $p=0.2$ ; Table 2).

#### **4.5 Measures of exercise preference**

*i) Pain:* A one-way, repeated measures ANOVA was performed on the pain scores of the six pieces of exercise equipment used in this study. No statistically significant difference was found ( $p=0.9$ ,  $\eta^2=0.3$ , Table 3).

*ii) Safety:* A one-way, repeated measures ANOVA was performed on the safety scores of the six pieces of exercise equipment used in this study. A significant main effect for equipment was found ( $p=0.00$ ,  $\eta^2=0.4$ ), however the Bonferroni post-hoc testing showed no significant differences in safety between any of the pieces of equipment (Table 3).

*iii) Enjoyment:* A one-way, repeated measures ANOVA was performed on enjoyment of the six pieces of exercise equipment used in this study. No significant main effect for equipment was found for enjoyment ( $p=0.5$ ,  $\eta^2=0.2$ , Table 3).

*iv) Exercise Frequency:* A one-way, repeated measures ANOVA was performed on the exercise frequency on all six pieces of exercise equipment. No significant main effect for equipment was found for exercise frequency ( $p=0.95$ ,  $\eta^2=0.2$ , Table 3). The current exercise guidelines for individuals with MS (Latimer- Cheung et al., 2013) suggest the minimum required exercise frequency is two times per week. The participants felt they could use the exercise equipment in adherence with MS exercise frequency



guidelines Table 3).

v) *Exercise Duration:* A one-way repeated measures ANOVA was performed on the exercise duration on all six pieces of exercise equipment. No significant main effect was found for exercise duration ( $p=0.3$ ,  $\eta^2=0.1$ , Table 3). The current exercise guidelines for individuals with MS (Latimer-Cheung et al., 2013) suggest a minimum required duration of 30 minutes per session. However none of the participants in the study felt they could use the equipment for the duration suggested by the MS exercise guidelines (Table 3).

## **Chapter 5: Discussion**

The main finding from this study was that combined arm and leg exercises (BWSTT, FES-LA, and NuStep) were more aerobically demanding than the arm-only exercise (arm ergometry) when performed at moderate intensity exercise. This was evidenced by a significantly higher submaximal  $\text{VO}_2$  during NuStep, FES-LA and BWSTT exercise compared to the submaximal  $\text{VO}_2$  during arm ergometry. Further, exercises using FES added no additional aerobic benefit compared to non-FES exercise modalities in the three submaximal intensity comparisons. In addition, there was no preference of exercise modality by the participants, which was evidenced by no significant differences in pain scores ( $p=0.9$ ), safety scores ( $p > 0.05$ ) or enjoyment on the exercise preference questionnaire ( $p=0.5$ ). All equipment met MS exercise guidelines for frequency, indicating that participants would adhere to the exercise frequency guidelines for MS on each piece of equipment. However, none of the exercise

equipment used in this study met exercise duration guidelines, indicating that the participants did not find any of the exercises sustainable for a 30-minute duration.

### **5.1 Comparisons of aerobic demand during moderate exercise**

This was the first study to compare the submaximal aerobic energy cost of various exercise modalities in individuals with MS. There are no other submaximal values available to directly compare the current results to. However, it is important to examine submaximal intensities, as this is realistically what individuals with MS will be doing in accordance to MS exercise guidelines. Furthermore, current research regarding exercise interventions available for this population is limited (Latimer-Cheung et al., 2013), which makes it difficult to compare the submaximal aerobic demand of the exercise equipment found in this study to values in the current literature.

It is promising that there were no statistical differences in submaximal aerobic demand between the exercise modalities tested, with the exception of arm ergometry. This suggests that all exercise modalities used in this study, with the exception of arm ergometry, are similar to each other in their ability to elicit an aerobic stimulus when used at a submaximal intensity. The current results are comparable to a study by Pelletier and colleagues (2014), where submaximal aerobic demand was tested on various types of accessible exercise equipment in individuals with spinal cord injury. The equipment tested included an arm ergometer, arm glider, arm-leg recumbent stepper, and arm-leg cycle ergometer, and no differences were found in submaximal aerobic demand when exercising at a moderate to vigorous intensity, as indicated by RPE. However, our results differed to the Pelletier and colleagues study (2014), as they did not find any aerobic

differences between arm ergometry and the NuStep arm-leg recumbent exercise. One explanation for this may be that in the study by Pelletier et al. (2014), the overall RPE scores were more variable than in the current study. In the study by Pelletier and colleagues (2014), participants were asked to exercise between 3-6 on the ten point Borg's scale, which corresponds to a range of "moderate" to "very hard" intensity. In the present study, intensity was sustained once the participant exercised between 11-13 on the 6-20 Borg's scale. This corresponds to "light" to "somewhat hard" intensity. Therefore, this study may have controlled variations in RPE more restrictively as the mean RPE was 12 points for every piece of equipment, indicating a very consistent perceived intensity between all pieces of exercise equipment tested (table 4). The tight control of variability may explain why a significant difference was detected in this study compared to the Pelletier and colleagues (2014) study. Furthermore, anecdotal comments from our participants support that in a sample with MS, arm ergometry may be more fatiguing than the NuStep exercise. Following the arm ergometer exercise session, participants commonly reported that they felt "more tired" and "drained" following the arm ergometer session than the other exercises they had completed testing. However, fatigue was not measured in this study to determine whether the effects of fatigue on the arm ergometer were related to lower  $\text{VO}_2$  at submaximal intensities. Therefore, considering Pelletier and colleagues (2014) used a sample with SCI, the effects of fatigue may be another key difference between distinguishing the two studies.

The arm ergometer and the FES-A used in this study focus on the smallest major muscle groups to produce a moderate intensity aerobic exercise compared to the other four pieces of equipment. However, the arm ergometer produced less of an aerobic

stimulus than the BWSTT and the arm-leg recumbent stepper, whereas the FES-A was found to be equivalent to BWSTT and the arm-leg recumbent stepper (figure 2). In a study by Mostert and Kesselring (2002), excessive fatigue (as indicated by the fatigue severity scale) during bicycle aerobic exercise was found to be 67% greater in a group with MS compared to a control group of healthy individuals. Furthermore, a study by Haan and colleagues (2000) examined the contractile properties of muscle in individuals with MS by using FES. They found that larger reductions in muscle performance occurred during voluntary exercise due to greater central fatigue, while FES allowed for exercise to occur at a higher resistance for a longer period of time. The findings from Haan and colleagues (2000) are in line with the results of the current study, as the addition of FES in the FES-A exercise may have prevented excessive central fatigue during steady-state exercise. In this instance, the addition of FES to arm cycling may have benefited steady state exercise by preventing central fatigue, as using FES allows for an involuntary muscle contraction bypassing the central nervous system. Likewise, during arm ergometry, maintaining moderate intensity exercise until steady state is achieved may have caused too much central fatigue. This could explain why moderate exertion on the arm ergometer was not as aerobically demanding as moderate exertion on the FES-A when comparing them to the BWSTT and the arm-leg recumbent stepper. Central and peripheral fatigue was not measured in the current study, so future research will be required to address this theory.

## **5.2 Comparisons of aerobic demand during maximal exercise**

VO<sub>2</sub> peak was measured on the arm-leg recumbent exercise, and the FES-LA exercise equipment, which were hypothesized to elicit the highest aerobic demand during

maximal intensity exercise. In the present study, the mean  $\text{VO}_2$  peaks achieved on the arm-leg recumbent exercise and the FES-LA were  $19.2 \pm 1.0 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ , and  $18.0 \pm 1.1 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ , respectively. These values are comparable to  $\text{VO}_2$  peak values achieved in a study performed by Morrison and colleagues (2008), where  $\text{VO}_2$  peak testing was done to test the reliability of RPE in individuals with MS. In their study, participants exercised using a leg ergometer. The mean  $\text{VO}_2$  peak value achieved by individuals with MS was  $22.9 \pm 6.2 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ . The slightly higher  $\text{VO}_2$  peak values achieved in their study were most likely a result of a participant group that was lower on the EDSS scale. Individuals were excluded if their EDSS score was higher than 3, where the EDSS scores in the current study ranged from 4 to 6.5, and it is well accepted that aerobic capacity decreases with increasing MS severity, as indicated by this scale (Langeskov-Christensen et al., 2014). Therefore, the arm-leg recumbent exercise and the FES-LA equipment may be effective to perform  $\text{VO}_2$  peak testing in individuals with MS that have a higher disability score, as indicated by the EDSS.

The  $\text{VO}_2$  peak values on the arm-leg recumbent stepper and FES-LA were not statistically significantly different, indicating that both pieces of equipment were equal at eliciting a peak aerobic response. This result differed from the proposed hypothesis, as it was expected that the addition of FES to the exercise would induce a greater aerobic response than the non-FES alternative. One possible explanation for this is that our participant sample was too low on the EDSS scale (mean EDSS score of 5.4) to detect peak aerobic benefits of FES exercise. This EDSS score indicates that the average participant is ambulatory without an aid for at least 200 meters. Therefore, these participants may not have muscles that are partially paralyzed to an extent where the

addition of FES would supplement their aerobic exercise and allow them to reach a higher peak stimulus. Future large-scale studies should separate samples by EDSS severity in order to detect if the FES is beneficial at higher EDSS scores.

### **5.3 FES and aerobic exercise**

In the current study, the addition of FES to an exercise did not significantly affect aerobic demand in both submaximal and peak tests. There are currently no other studies that have compared how the addition of FES affects the aerobic demand of traditional modalities at either submaximal or maximal workloads in individuals with MS. However, a study by Deley and colleagues (2008) compared the effects of FES exercise to traditional exercise on aerobic fitness measures in individuals with chronic heart failure. Participants were allocated to either a FES group or conventional exercise-training group. Both exercise groups participate in a one-hour exercise session five days a week for five weeks. The conventional training group and the electrical stimulation groups used traditional aerobic exercises during the exercise sessions, such as treadmill and bicycle training. The FES group had low-frequency stimulation applied to their quadriceps and soleus muscles, which trained the muscles in intervals of 12s on and 8s off.  $\text{VO}_2$  peak was measured before and after the exercise intervention. Both groups had significant improvements in  $\text{VO}_2$  peak, however there was no additional aerobic benefit to using the FES exercise equipment compared to the conventional equipment, which is consistent with the findings of our study. Our findings support that both traditional and FES equipment are ideal forms of aerobic exercise in the MS population, as the aerobic benefits are similar using both modalities.

Our findings do not support our initial hypothesis that the addition of FES would require higher aerobic demand at any given exercise intensity. It is possible that electrically stimulated muscle contractions provide the same aerobic demand as a traditional muscle contraction regardless of muscle paralysis. In this instance, FES exercise would be aerobically beneficial to the same extent as non- FES exercise.

#### **5.4 Limiting factors of FES**

Sensation may be a limiting factor for providing optimal electrical stimulation for exercise. In an ideal FES exercise set-up, the electrodes are set to stimulate tetanic contractions of the muscles. However, this was not always possible in our study as some of the participants experienced discomfort from the stimulation before a tetanic contraction was produced. Therefore, muscle stimulation was below optimal for each exercise session.

Furthermore, for the  $\text{VO}_2$  peak tests, participants with a lower EDSS score may not have achieved a true  $\text{VO}_2$  peak, as the maximum resistance and speed on the equipment may have been reached before the participant was at their maximal exercise intensity. On another note, maximal exercise intensity on the FES equipment in this study was limited as the highest speed attainable was 50 rpm, and surpassing this speed results in decalibration of the stimulation from the exercise movement. Likewise, the maximum possible resistance was 15.0 Nm at any given speed on the equipment. As a result, seven participants in this study did not attain a maximal exercise capacity. In fact, once the limits of these machines were reached, equipment related issues arose (such as the pedals on the FES-LA machine desynchronizing from the exercise program). Hence, further

development of this equipment should focus on providing higher exercise intensities, so individuals with less severe MS can still utilize these machines for optimal aerobic exercise benefits, especially when the equipment is being used at  $\text{VO}_{2\text{ peak}}$  exercise intensity.

### **5.5 Applicability to exercise guidelines**

All exercises in this study were similar in regards to pain experienced, perceived safety using the equipment and level of enjoyment. Therefore, the arm-leg recumbent stepper, FES-leg cycle, FES-arm cycle, FES arm-leg recumbent stepper, and BWSTT are all considered appropriate exercise modalities to include in an aerobic exercise program for people with MS.

All equipment used in this study, with the exception of the arm ergometer were similar in their ability to elicit an aerobic stimulus. Practically and realistically however, not all equipment tested is suitable for home or unsupervised use. The arm ergometer was an inferior aerobic exercise when compared to the other five machines, but is safe to be used at home or in a therapy setting. An arm ergometer requires little to no supervision and individuals with severe disability can set themselves up independently, making it an important piece of exercise equipment regardless of its inability to induce similar cardiovascular response as the other equipment.

The BWSTT can only be used with full supervision during setup, the entirety of the exercise session, and after session completion. This machine requires a minimum of two assistants at all times. Although the BWSTT was comparable to the other equipment, it is important to note that it may not be the most feasible modality considering the



aerobic benefits are similar to other more self-reliant exercise equipment, such as the arm-leg recumbent stepper (NuStep). The arm-leg recumbent stepper (NuStep) may be of particular utility for individuals with mild to moderate disability, as it can be independently used, or easily and quickly set up by an assistant, and elicits the same aerobic benefits as the other equipment tested in this study.

In regards to the FES exercise modalities, the equipment can be used independently once the individual has been trained on the device. Further, using FES may be appropriate for individuals with moderate to severe MS, as there are additional benefits of an aerobic exercise using muscle stimulation in muscles that are fully or partially paralyzed such as: increasing blood flow to these muscles, increasing muscle mass and reducing spasticity (Peckham and Knutson, 2005).

## **5.6 Limitations and future directions**

The primary limitation of the current study was its small sample size. Considering the inclusion criteria for this study was very narrow and specific, the pool of individuals with MS that were eligible for this study was small and limited to one geographic region, as participants had to be available multiple times for testing. However, given the scientific necessity of such a narrow inclusion criteria, we feel that the study still has importance in this small but important subgroup of MS patients.

Another limitation is the fact that the findings from this study are only applicable to individuals with MS who are currently ambulatory or semi-ambulatory, with an EDSS score of less than 8. This may be perceived as a limitation, however the current CSEP and MS society exercise guidelines in fact focus on this same group of individuals suffering

from MS. Furthermore, the traditional exercise modalities used in this study require some volitional effort in order to exercise. Therefore, these exercises may not be ideal for individuals with a higher EDSS score. Future research should examine whether the FES exercise equipment used in this study can elicit an aerobic response in individuals with MS who are non-ambulatory (EDSS>8). By doing so, this acquired knowledge will help to expand the current MS exercise guidelines to a more severely disabled population.

As for future studies, they should also include perceptions of fatigue on various modalities of exercise equipment during a sustained aerobic exercise, and its relation perceived intensity using the RPE scale. Furthermore, comparing the effects of fatigue in FES exercises compared to the traditional modalities during moderate intensity exercise in different EDSS scale groups may be key in identifying when FES exercises are best used in an exercise prescription for MS. Answering these questions in an MS population may lead to maximizing the utility and efficacy of aerobic exercise, inform and advance the MS exercise guidelines in a consumer-centered manner, and improve the sustainability of exercise programs over time.

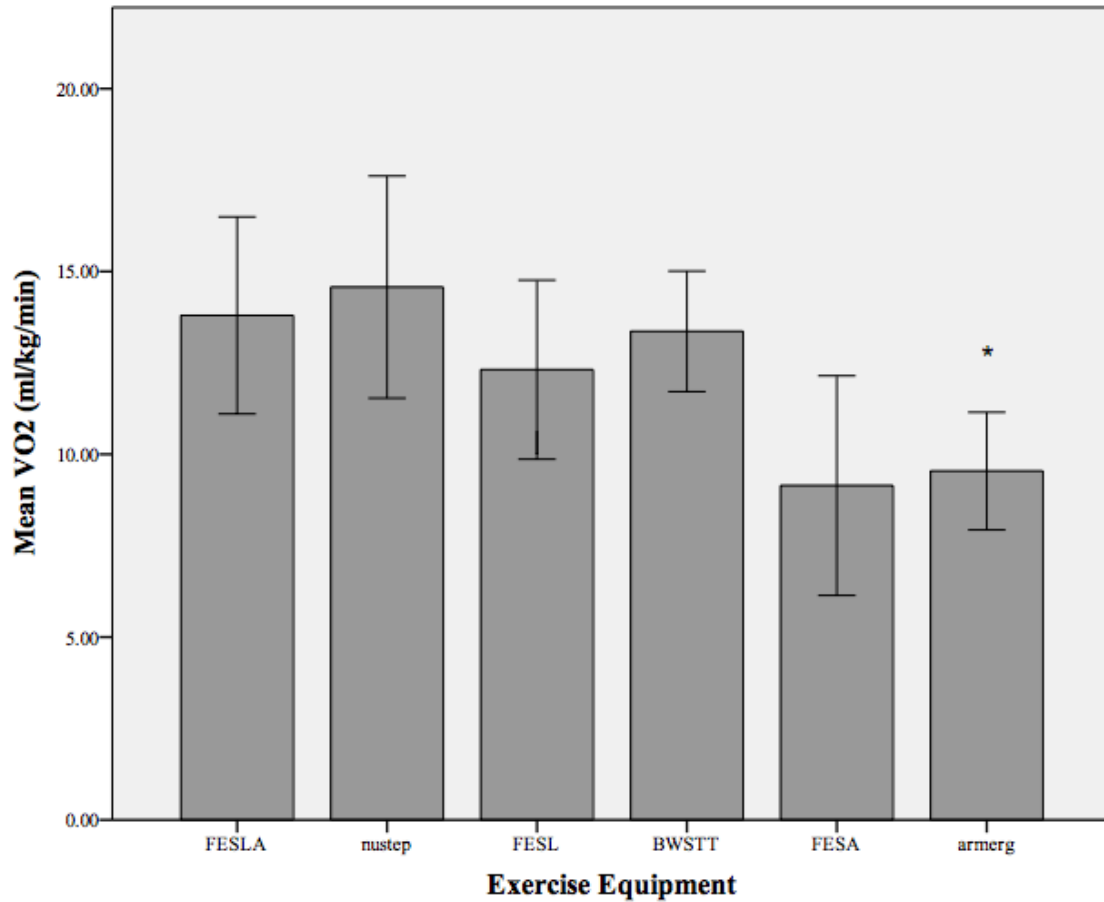
## Figures and Tables

**Table 1.** Participant characteristics

| #  | Age<br>(years) | Sex | Type of<br>MS | Years-post<br>Diagnosis | EDSS | Height<br>(cm) | Body Mass<br>(kg) |
|----|----------------|-----|---------------|-------------------------|------|----------------|-------------------|
| 1  | 58             | F   | SPMS          | 36                      | 6    | 156            | 59                |
| 2  | 36             | M   | RRMS          | 5                       | 5    | 189            | 94                |
| 3  | 46             | F   | RRMS          | 2                       | 5    | 167            | 89                |
| 4  | 56             | M   | SPMS          | 22                      | 6.5  | 166            | 59                |
| 5  | 49             | F   | SPMS          | 38                      | 6    | 160            | 58                |
| 6  | 61             | F   | RRMS          | 16                      | 6    | 175            | 105               |
| 7  | 43             | F   | RRMS          | 9                       | 6    | 169            | 112               |
| 8  | 41             | F   | RRMS          | 8                       | 4    | 165            | 65                |
| 9  | 58             | F   | SPMS          | 24                      | 6.5  | 169            | 108               |
| 10 | 61             | F   | PPMS          | 4                       | 4    | 160            | 74                |

Abbreviations: MS, multiple sclerosis, EDSS, expanded disability status scale, SPMS, secondary progressive multiple sclerosis, RRMS, relapsing remitting multiple sclerosis, PPMS, primary progressive multiple sclerosis, F, female, M, male

**Figure 1.** A comparison of the submaximal aerobic demands of each piece of exercise equipment.



Abbreviations: VO<sub>2</sub>, volume of oxygen, FESLA, functional electrical stimulation arm leg exercise, FESL functional electrical stimulation leg exercise, BWSTT, body weight support treadmill training, FESA, functional electrical stimulation arm exercise, ACE, arm crank ergometry

Values are the mean  $\pm$  s.d.

\* Denotes a significantly lower VO<sub>2</sub> value for ACE compared to each of: FES-LA, NuStep, BWSTT.

**Table 2.** Comparisons between the FES vs. non-FES equipment for submaximal aerobic demand.

| <b>Exercise equipment</b> | <b>VO<sub>2</sub> (ml·kg<sup>-1</sup>·min<sup>-1</sup>)</b> | <b><i>p</i>-value</b> | <b>% VO<sub>2</sub> peak</b> | <b><i>p</i>-value</b> | <b><i>d</i></b> |
|---------------------------|---|-----------------------|------------------------------|-----------------------|-----------------|
| Arm-ergometer             | 9.54 ± 0.7  | 0.77                  | 47.7 ± 11.0                  | 0.72                  | 0.12            |
| FES-A                     | 9.14 ± 1.2  |                       | 45.0 ± 21.1                  |                       |                 |
| NuStep                    | 14.57 ± 1.3   | 0.23                  | 71.8 ± 15.7                  | 0.36                  | 0.19            |
| FES-LA                    | 13.79 ± 1.2   |                       | 68.4 ± 15.1                  |                       |                 |
| BWSTT                     | 13.36 ± 0.7   | 0.24                  | 67.2 ± 12.4                  | 0.21                  | 0.36            |
| FES-L                     | 12.31 ± 1.1   |                       | 61.5 ± 17.0                  |                       |                 |

Abbreviations: VO<sub>2</sub>, volume of oxygen, FES-A, functional electrical stimulation arm exercise, FES-LA, functional electrical stimulation arm leg exercise, BWSTT, body weight supported treadmill training, FES-L, functional electrical stimulation leg exercise. *d*, cohen's d effect size.

Values are mean ± s.d.

**Table 3.** One-way repeated measures ANOVA comparing preference of each piece of exercise equipment.

|                        | <b>AE</b>  | <b>FES-A</b> | <b>NuStep</b> | <b>FES-LA</b> | <b>BWSTT</b> | <b>FES-L</b> |
|------------------------|------------|--------------|---------------|---------------|--------------|--------------|
| <b>Sample Size</b>     | 10         | 10           | 10            | 10            | 10           | 10           |
| <b>Used Previously</b> | 3          | 0            | 4             | 1             | 2            | 2            |
| <b>Pain</b>            | 6.8 ± 3.8  | 6.9 ± 3.4    | 6.0 ± 3.1     | 5.9 ± 3.5     | 6.5 ± 3.3    | 6.3 ± 3.0    |
| <b>Enjoyment</b>       | 4.1 ± 2.1  | 5.1 ± 1.5    | 6.2 ± 1.2     | 5.8 ± 1.2     | 5.3 ± 2.0    | 4.7 ± 1.7    |
| <b>Safety</b>          | 12.6 ± 1.9 | 11.3 ± 3.5   | 12.8 ± 1.8    | 9.8 ± 3.9     | 7.8 ± 4.6    | 9.1 ± 3.6    |
| <b>Minutes</b>         | 14.5 ± 7.2 | 16.0 ± 6.1   | 18.5 ± 5.8    | 19.0 ± 8.1    | 14.6 ± 6.6   | 16.0 ± 7.4   |
| <b>Times/week</b>      | 2.5 ± 1.3  | 2.7 ± 0.8    | 3.6 ± 1.3     | 2.8 ± 0.9     | 2.3 ± 1.3    | 2.5 ± 0.8    |

Abbreviations: AE, arm ergometer, FES-A, functional electrical stimulation arm exercise, FES-LA, functional electrical stimulation arm leg exercise, BWSTT, body weight supported treadmill training, FES-L, functional electrical stimulation leg exercise.

Values for pain, enjoyment, safety, minutes and times/week are means ± s.d.

Values for Used Previously are the number of participants in the sample that have experience with the piece of equipment.

**Table 4.** Mean RPE scores on each piece of exercise equipment during submaximal exercise.

|                      | Mean RPE | Median RPE |
|----------------------|----------|------------|
| <b>Arm ergometer</b> | 12.7±0.7 | 13         |
| <b>FES-A</b>         | 11.4±1.3 | 11         |
| <b>Nustep</b>        | 12.3±1.0 | 12.5       |
| <b>FES-LA</b>        | 12.1±1.4 | 13         |
| <b>BWSTT</b>         | 12.5±0.7 | 13         |
| <b>FES-L</b>         | 12.5±0.7 | 13         |

Abbreviations: RPE, rate of perceived exertion, FES-A, functional electrical stimulation arm exercise, FES-LA, functional electrical stimulation arm leg exercise, BWSTT, body weight supported treadmill training, FES-L, functional electrical stimulation leg exercise.  
Values are means ± s.d.

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## **Appendix A**

### **EDSS Scale (Kurtzke, 1983)**

0= Normal neurologic exam (all grade 0 in functional systems [FS]; cerebral grade 1 acceptable)

1.0= No disability, minimal signs in one FS (ie. grade 1 excluding cerebral grade 1)

1.5= No disability minimal signs in more than one FS (more than one grade 1 excluding cerebral grade 1)

2.0= Minimal disability in one FS (one FS grade 2, others 0 or 1)

2.5= Minimal disability in two FS (two FS grade 2, others 0 or 1)

3.0 Moderate disability in one FS (one FS grade 3, others 0 or 1), or mild disability in three or four FS (three/four FS grade 2, others 0 or 1) though fully ambulatory.

3.5= Fully ambulatory but with moderate disability in one FS (one grade 3) and in one or two FS grade 2; or two FS grade 3/ or five FS grade 2 (others 0 or 1).

4.0= Fully ambulatory without aid, self-sufficient, and about some 12 hours a day despite relatively severe disability consisting of one FS grade 4 (others 0 or 1), or combinations of lesser grades exceeding limits of previous steps. Able to walk without aid or rest some 500 meters.

4.5= Fully ambulatory without aid, up and about much of the day, able to work a full day, may otherwise have some limitation of full activity or require minimal assistance; characterized by relatively severe disability, usually consisting of one FS grade 4 (others 0 or 1) or combinations of lesser grades exceeding limits of previous steps. Able to walk without aid or rest for some 300 meters.

5.0= Ambulatory without aid or rest for about 200 meters; disability severe enough to impair full daily activities (eg. to work full day without special provisions). (Usual FS equivalents are one grade 5 alone, others 0 or 1; or combinations of lesser grades usually exceeding specifications for step 4.0)

5.5= Ambulatory without aid or rest for about 100 meters; disability severe enough to preclude full daily activities (Usual FS equivalents are one grade 5 alone, others 0 or 1; or combination of lesser grades usually exceeding those for step 4.0).

6.0= Intermittent or unilateral constant assistance (cane, crutch, or brace) required to walk about 100 meters with or without resting. (Usual FS equivalents are combinations with more than two FS grades 3+).

6.5= Constant assistance (canes, crutches, or braces) required to walk about 20 meters without resting. (Usual FS equivalents are combinations with more than two FS grades 3+).

7.0= Unable to walk beyond about 5 meters even with aid, essentially restricted to wheelchair; wheels self in standard wheelchair and transfers alone; up and about in wheelchair some 12 hours a day.

7.5= Unable to take more than a few steps; restricted to wheelchair; may need air in transfer; wheels self but cannot carry on in standard wheelchair a full day; may require motorized wheelchair.

8.0= Essentially restricted to bed or chair or perambulated in wheelchair, but may be out of bed itself much of the day; retains many self-care functions; generally has effective use of arms.

8.5= Essentially restricted to bed much of the day' has some effective use of arm (s); retains some self-care functions.

9.0= Helpless bed patient; can communicate and eat.

9.5= Totally helpless bed patient; unable to communicate effectively or eat/swallow.

10= Death due to MS.



## **Appendix B**

### **Borg's Scale of Rating of Perceived Exertion**

|    |                    |
|----|--------------------|
| 6  | No exertion at all |
| 7  | Extremely light    |
| 8  | Extremely light    |
| 9  | Very light         |
| 10 |                    |
| 11 | Light              |
| 12 |                    |
| 13 | Somewhat hard      |
| 14 |                    |
| 15 | Hard (heavy)       |
| 16 |                    |
| 17 | Very hard          |
| 18 |                    |
| 19 | Extremely hard     |
| 20 | Maximal exertion   |

## Appendix C

### **Equipment Preference Questionnaire**

(Pelletier C., Latimer-Cheung A. & Hicks A., 2014)

#### **Pain**

1. How much shoulder pain did you feel?

No pain      1      2      3      4      5      6      7      Extreme Pain

2. How much bodily pain & physical discomfort do you typically experience?

No pain      1      2      3      4      5      6      7      Extreme Pain

3. How much bodily pain & physical discomfort did you feel using this specific piece of equipment?

No pain      1      2      3      4      5      6      7      Extreme pain

#### **Safety -**

1. How confident are you in your ability to use each piece of exercise equipment?

a) Without assistance?

No confident      1      2      3      4      5      6      7      Fully capable

b) Safely without causing injury?

No confident      1      2      3      4      5      6      7      Fully capable

#### **Enjoyment-**

1. How much did you like using this specific piece of exercise equipment?

Do not like it 1      2      3      4      5      6      7 Liked a lot

#### **(SCI) Exercise Guidelines**

1. Assuming you are very motivated & fit, how many times per week could you imagine yourself using this piece of equipment?

a) 1    b) 2    c) 3    d) 4    e) >4

2. How many minutes could you imagine yourself using this specific piece of exercise equipment?

a) <5min      b) 5min c) 10min      d) 15min      e) 20min      f) 25min  
g) 30min      h) other \_\_\_\_\_